Discussion on the Energy-Saving Potential of a Hybrid System in a Large Space Building in Different Areas[1]

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Abstract: The use of a hybrid ventilation system is promoted to decrease the annual energy consumption of air conditioning. The switch-point of temperature, which is related with weather conditions, is presented to control the hybrid system properly. An industrial factory was provided with the hybrid ventilation system using different weather conditions in three typical areas—Beijing, Shanghai and Guangzhou—to determine the energy-saving potential in different areas. The results of research in this paper show that, of the three areas, Shanghai has the highest energy-saving potential, while Guangzhou has the lowest.

Key words: hybrid ventilation system; switch temperature; energy-consumption; energy-saving

1. INTRODUCTION

From the former reports[1][2], it has known that the amount of energy-saving of the hybrid ventilation system is related with the switch temperatures. The duration between the two switch temperatures is defined as the intermediate season without air conditioning. The longer the intermediate season, the more the annual energy consumption, and the less the amount of energy-saving. In this paper, we apply the hybrid environment system to an industrial factory using the meteorological data to find out the energy-saving potential in the three different areas (the north Beijing, the middle Shanghai and the south Guangzhou).

2. THE IDEA OF THE HYBRID SYSTEM

2.1 The Concept of Switch Temperature

During the intermediate season, indoor cooling load will decrease when outdoor temperature is going down; meanwhile exhausted heat rate by ventilation will increase. If cooling load is equal to exhausted heat rate, the ventilation can maintain an acceptable indoor air quality effectively. For a given range of indoor air temperature (e.g. 19~26°C), we can define two outdoor temperatures as switch temperatures t_{wc} and t_{wh} between which the indoor temperature can be kept at the given desired region by ventilation[1]. That is, if the outdoor temperature lies between t_{wh} and t_{wc}, the use of ventilation can keep IAQ and discharge the exhausted heat, and a comfortable indoor temperature can be maintained.

2.2 The Correct of the Switch Temperature t_{wh}

It is reasonable to use designed air rate of air conditioning system to meet the ventilation needs in intermediate season, but this often makes excessive air volume than that of sanitary demands. When t_w is low, we can reduce the air rate to decrease the heat release by ventilation, therefore the switch temperature t_{wh} can be decreased, resulting in a prolongation of ventilation period. For example, for a mechanical ventilation system with multiple fans, it is convenient to turn off some of the fans to reduce the air rate when outdoor temperature is the lower switch temperature. This air rate can also be given by mixing an amount of return air with fresh air for decreasing t_{wh} at a larger extent. Depending on the sanitation demands, the t_{wh} can be corrected. The annual duration of intermediate season can be expressed by the temperature difference between t'_{wh} and t_{wc} solved by the following equations:

$$a_1 t'_{wh} + b_1 = G_{lim}\,(i_{n1} - i'_{wh}) \times 1000/F \quad (1a)$$

$$a_2 t_{wc} + b_2 = G_s\,(i_{wc} - i_{n2}) \times 1000/F \quad (1b)$$

where G_{lim} —— lowest air rate due to sanitary demands and simple control (kg/s);

G_s —— ventilating air rate (kg/s);

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a_i, b_i —— coefficients calculated by indoor air parameter with BIN method[1];
t'_{wh}, i'_{wh} —— the corrected lower limit switch temperature (°C) and enthalpy (kJ/kg);
t_{wc}, i_{wc} —— the upper limit switch temperature (°C) and enthalpy (kJ/kg);
i_{n1}、i_{n2} —— the lower and upper enthalpy for indoor permitted temperature (kJ/kg);
F —— the air conditioned area (m^2).

2.3 Consideration of Comfort on Indoor Enthalpy

When the period of intermediate season close to winter, a large amount of outdoor air enter into the room by ventilation. The indoor air may become too dried to comfort. It is necessary to set up Eq.(2) for humidity in order to maintain a comfortable humidity environment. Indoor enthalpy can be given by Eq.(2) and t_{n1}. If the indoor humidity is low at t_{wh}, it is possible to reduce the air rate directly to meet the demands of thermal comfort.

$$d_{n1}=d'_{wh}+(W+\Delta W)/G_{lim} \quad (2)$$

where

d'_{wh}, d_{n1} —— the lower limit switch humidity and the lower indoor permitted humidity (g/kg);
W, ΔW —— indoor moisture load and humidifying amount for comfort (g/s).

3. THE APPLICATION OF THE HYBRID VENTILATION IN THREE AREAS

3.1 Bin Parameters of Three Areas

The amount of energy-saving of the hybrid system is related with the weather condition, mainly the hours of duration at a certain temperature. The BIN Method gives a series of the statistic hours at different temperatures. At present, there are two perfect meteorological data. The former is provided by Lawrence Berkley National Lab of DOE, and the latter is offered by Weather Statistics Center of China Weather Bureau[3]. This paper uses the latter for analyzing to obtain BIN parameters of the three areas, which will be reported in another paper. Tab.2 lists a part of BIN Parameters in the three areas.

3.2 Intermediate Seasons of One Actual Workshop

The building area and air-conditioned area of one workshop are 15000m^2 and 11250m^2 respectively, and the height is 12.5m. Designed temperatures are 19℃in winter and 26℃in summer with 50% relative humidity. Indoor heat sources are determined by 130 workers, equipments and illumination. Designed cooling load is 1280 kW and it is necessary to supply cold air under the rated condition of winter. The air rate supplied by five independent air conditioning systems is 400,000 m^3/h. Each system has one supply fan and one extract fan. Therefore, the lowest air rate is the air rate of one fan, and the highest air rate is that of five fans. Since the working time of the workshop is 24 hours a day, it is possible to calculate the energy saving by 24hr BIN parameters.

According to the meteorological data of Shanghai, if indoor cooling load reaches 80% of its designed value and the indoor temperature is 19°C and 26°C , which relative humidity is about 40%～65%, the values of CLQ and Q_p in intermediate seasons can be obtained by Eq.(3) and Eq.(4).

$$CLQ_{19}=1.26t_w+53.7 \quad (3a)$$
$$CLQ_{26}=1.26t_w+45.6 \quad (3b)$$
$$Q_{p19}=81.8-2.4i'_{wh} \quad (4a)$$
$$Q_{p26}=617.7-12.0i_{wc} \quad (4b)$$

From the results of calculation, we find that the air conditioning system should be turn on for heating when t_w<3.1°C and for cooling when t_w>18.0°C. For the case of 3.1°C ≤ t_w ≤ 18.0°C, the mechanical ventilation using the air conditioning duct system is more efficient to maintain the indoor temperature in a given region. Actually, t'_{wh} can be also calculated by

Tab. 2 BIN Parameters of Beijing, Shanghai and Guangzhou (working time:24hr/day)

Beijing	Hours	15	64	134	235	320	386	430	412	428	388	461	368	415
Shanghai						0	34	64	113	298	512	529	580	571
Guangzhou											8	63	210	494
BIN parameters /℃		12	14	16	18	20	22	24	26	28	30	32	34	36
Beijing	Hours	467	459	432	487	508	553	614	453	366	216	109	35	5
Shanghai		501	486	543	544	628	845	670	717	609	334	130	38	13
Guangzhou		518	558	511	653	712	899	1381	1122	760	506	271	92	2

another operation model of one running-fan supplying the air mixed with return air. The fresh air proportion is 60% when the indoor load is 80% of its designed value. When the indoor load is 40% of the designed value, the percentage of the fresh air is 12%. If the indoor load is less than 40%, the air conditioning system should be put into operation.

The change range of t'_{wh}, t_{wc} with different load proportions are showed in Fig.1. The indoor air temperature is in a range of 19～26℃. t'_{wh} is determined on one running-fan condition and t_{wc} is predicted on five running-fans. It is clearly seen from Fig.1 that, with the load proportion increasing, t'_{wh}, t_{wc} will decrease while the difference between t'_{wh} and t_{wc} will increase. It is possible to extend intermediate season and shorten the duration of mechanical air-conditioning ventilation.

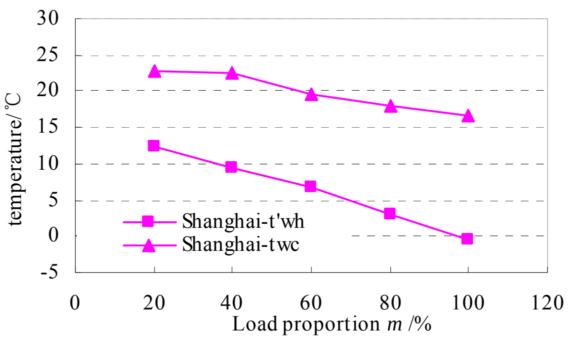


Fig.1 t_{wh}, t_{wc} with different load proportions in Shanghai

The three areas have the same switch temperatures approximately, which shows the switch temperatures are mainly determined by the indoor load proportions. Especially for the large workshop with large indoor load, the outdoor climate has little influence on the switch temperatures.

4. COMPARISON OF VENTILATION ENERGY-SAVING POTENTIAL IN THREE AREAS

4.1 Annual Refrigerant Energy-saving

The example is a typical steady-sustained industrial air conditioning model. The indoor load including occupants, illumination and equipments is 86% of designed cooling load so that the workshop is needed to be supplied with cold air in winter, so the hybrid ventilation system is useful to the workshop.

There are different hours of temperature frequency with different outdoor temperature in different areas by its BIN parameters, even if there is the similar duration of the intermediate season. It can be seen that the amount of the energy-saving of the hybrid system is affected largely by a number of factors, such as indoor load proportion and the hours of temperature frequency with different outdoor temperature in intermediate season. The energy-saving potential of intermediate seasons can be analyzed by following variables. Load proportion can be defined as the following equation:

$$m = CLQ_0(m)/\ CLQ_0(n) \tag{5}$$

Where $CLQ_0(m)$ is the indoor load of occupants, illumination and equipments and $CLQ_0(n)$ is designed load. The energy-saving efficiency can be defined as the following equation:

$$\gamma = \Delta E\ (m)/E\ (m) \tag{6}$$

where $E\ (m)$ is the annual energy consumption for air conditioning when the load proportion is m.

By taking the BIN parameters listed in Tab.1, ΔE, which is the annual refrigerant energy saving with the use of mechanical ventilation, can be introduced by the following Equation:

$$\Delta E = \Sigma f_i \times CLQ_i \tag{7}$$

where f_i —— hours of temperature frequency with different outdoor temperature in intermediate season (h);

CLQ_i —— cooling load per air-conditioned area with different outdoor temperature (W/m^2).

4.2 Analysis on Energy-saving Potential

The relations between the energy-saving efficiency with different load proportions are showed in Fig.2. When the load proportion of workshop is larger than 0.4, the energy-saving efficiency of the different areas is affected more greatly than when the load proportion is less than 0.4. It is clear that with the load proportion increasing, the energy-saving efficiency is related more greatly with the climate features. With the load proportion of the workshop increasing, the energy-saving efficiency of the hybrid ventilation system increases in Shanghai but decreases in Guangzhou. When the load proportion is 1, in Shanghai and Guangzhou, the difference of their energy-saving efficiencies is about 20%. Among the three areas, Shanghai has the highest energy-saving potential, while Guangzhou has the lowest. It is because that the hours of the different temperature frequency of Shanghai in the intermediate season is the largest and that of Guangzhou is the lowest from Fig.3.

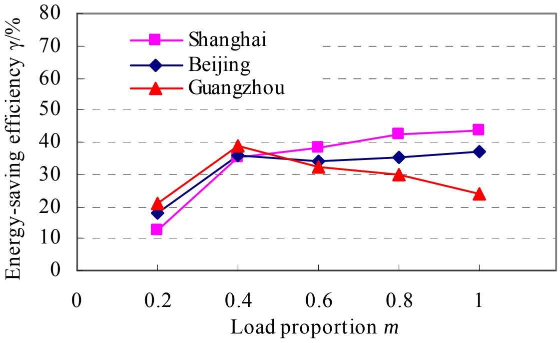
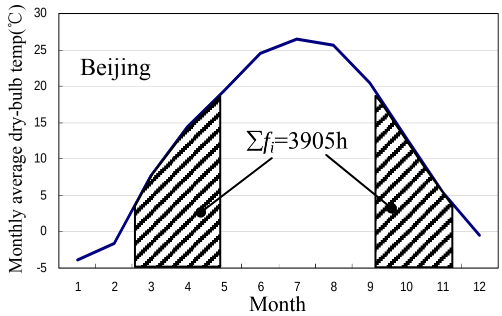
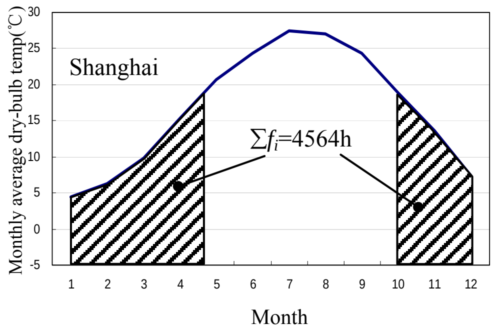


Fig. 2 Energy-saving efficiencies with different load proportions in the three areas





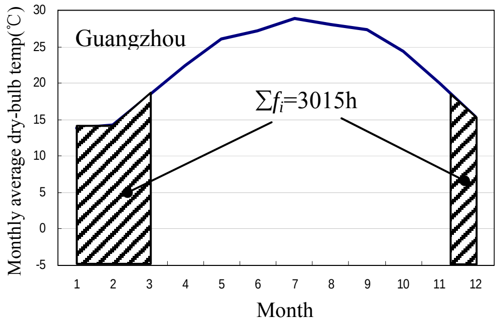


Fig. 3 Ventilation duration in the three areas

5. SUMMARY

1) The annual energy consumption for air conditioning in Beijing, Shanghai and Guangzhou is analyzed by their BIN parameters provided by this paper.

2) It is clear that when the load proportion of the workshop is larger than 0.4, the energy-saving efficiency will be affected greatly by the climate features.

3) Among the three areas, Shanghai has the highest energy-saving efficiency, while Guangzhou has the lowest.

Taking natural energy sources for cooling, which is not only benefit for better air quality, but also for reducing energy consumption, should be promoted greatly.

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